3.0 DESCRIPTION OF THE INCIDENT

3.1 PRE-INCIDENT EVENTS

On the evening of the incident, eight high-school-aged teens (including the son of one of the co-owners) gathered at the farm for a party. According to one of the co-owners of the farm, the youths had attended similar social gatherings at the farm on other dates, but with neither the knowledge nor the consent of the owners. Neither owner lived at the farm.

At approximately 11:00 pm, one of the youths began driving an all-terrain vehicle (ATV) around the farm. Then the driver of the ATV picked up a passenger and continued his ride. The ATV was heading east between the propane tank and a turkey barn when it struck the two aboveground propane pipes (liquid and vapor lines) that ran from the propane tank to direct-fired vaporizers approximately 37 feet to the north of the tank (See Figure 2). The ATV damaged both the liquid and vapor lines.

The liquid line (which measured approximately ¾-inch inside diameter) was completely severed from the tank at the location where it was connected to a manual shut-off valve directly beneath the tank (see Figure 6, item A20). An excess flow valve protecting the liquid line (see Figure 6, item FV3) failed to function, and propane leaked out of the tank at the point of the break. As the liquid propane sprayed out of the tank, it rapidly changed to vapor. Propane vapor may have also leaked from the damaged vapor line.[8] Propane from the damaged pipes formed a cloud, and within a few minutes this propane vapor ignited. Although the source of ignition was not conclusively established, the likely source was the direct-fired vaporizers.[9] A fire, fed by the broken liquid line, began burning vigorously under the tank.

Two of the teenagers drove to the home of a neighbor, approximately ½ mile from the farm, to report what had happened. At 11:10 pm, the neighbor called the 911 operator to report the fire.

[8] Although the vapor line was also damaged by the ATV and may have leaked some propane, CSB investigators found no conclusive evidence that damage to the vapor line otherwise contributed to the explosion. For further discussion of this issue, see section 4.6.

[9] Possible ignition sources from the direct-fired vaporizers include the pilot light, the burner flame, or a hot surface.

3.2 EMERGENCY RESPONSE

Twenty members of the Albert City Volunteer Fire Department and two Buena Vista County Sheriff Deputies were the first responders to reach the farm.[10] Upon arrival at about 11:21 pm, the fire fighters observed flames originating from two primary locations: from under the west end of the tank and from the pressure relief valve pipes located on the top of the tank. One fire fighter reported that the "west end of the tank [near the broken liquid line] was *engulfed* in flames" (emphasis added).[11] Another stated that "the propane tank was fully engulfed and flames were 70-100 yards in the air."[12] Because of the fire, the fire fighters did not attempt to reach the manual shut-off valve on the broken pipe (see Figure 6, item A20). Thus, the fire fighters could not stop the propane release, and the fire continued to burn out of control. Fire fighters stated that the noise from the relief valves was "like standing next to a jet plane with its engine at full throttle."[13]

The Chief of the Albert City Fire Department told one of Buena Vista County Deputies that the plan was to let the fire burn itself out and at the same time to water down the buildings adjacent to the tank.[14] Two fire fighter hose teams positioned themselves at different locations near a building located about 90 feet north from the side of the burning tank (see Figure 2, Building 1-G, and Figure 8, fire fighters 1, 2, 5, and 6). Fire fighters did not attempt to spray the tank with water. Instead, they set up to spray water from a fire truck onto the surrounding buildings, hoping to prevent the buildings from catching on fire. Because there was no source of fire-fighting water at the farm, one of the fire trucks was sent away to obtain more water.

At approximately 11:28 pm, the tank exploded. One of the responding Buena Vista County Deputies stated that he saw the tank swell before the blast. Immediately after observing the swelling of the tank, he heard a loud explosion. The tank and its associated piping were blown into at least 36 pieces. One of the large pieces traveled in a northwesterly direction, striking and

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[10] For a detailed description of the emergency response, see Duval, Robert. *Fire Fighter Fatalities Albert City Iowa April 9, 1998*; National Fire Protection Association: Quincy, MA, 1999.
[11] Buena Vista County Sheriff. *Buena Vista County Sheriff's Incident Report* (Incident Number 98-002070-I): Storm Lake, Iowa, 1998.
[12] *Ibid.*
[13] *Ibid.*
[14] *Ibid.*

killing two volunteer firemen. The Iowa State Medical Examiner listed the cause of death in each instance as massive trauma to all body systems. The fire fighters who died were located about 100 feet from the northwest side of the tank, as depicted in Figure 8 (numbers 1 and 2). The tank piece that struck two of the fire fighters narrowly missed the Fire Chief (see Figure 8, number 4). Another large piece of the tank was propelled directly north, just missing two other fire fighters (see Figure 8, numbers 5 and 6). Seven emergency response personnel sustained injuries as a result of the explosion. These injuries ranged from scrapes and bruises to severe burns.[15] This explosion easily could have caused numerous additional fire fighter fatalities.

[15] For additional information on the injuries sustained by emergency response personnel, see Duval, Robert. *Fire Fighter Fatalities Albert City Iowa April 9, 1998*; National Fire Protection Association: Quincy, MA, 1999, 12-14 and Buena Vista County Sheriff. *Buena Vista County Sheriff's Incident Report* (Incident Number 98-002070-I): Storm Lake, Iowa, 1998.

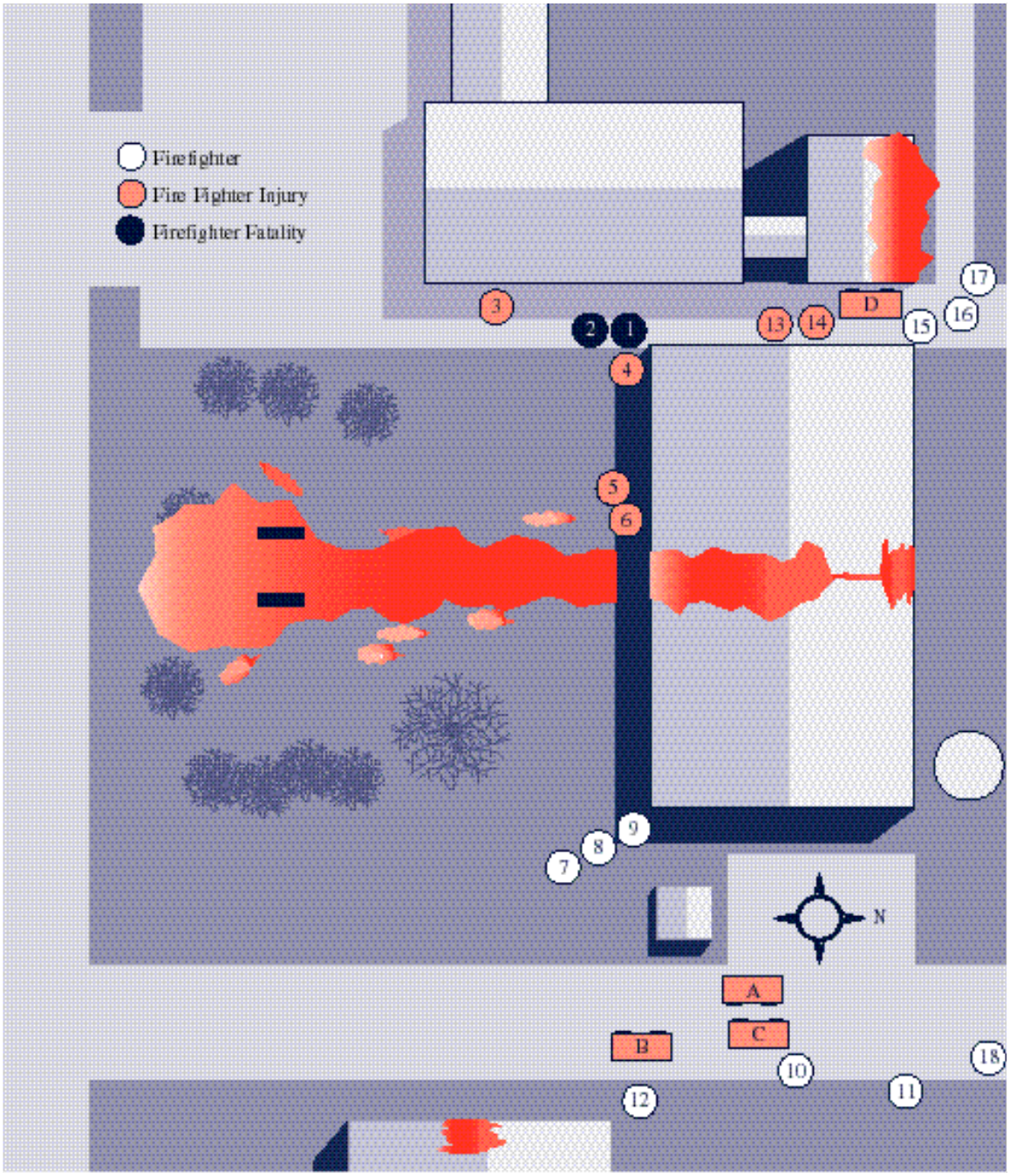

Figure 8. Fire fighters (numbers) and Response Vehicles (letters) at the Time of the Blast (not to scale)

3.3 BLEVE

3.3.1 Nature of a BLEVE

The explosion that occurred at the farm is known as a Boiling Liquid Expanding Vapor Explosion or BLEVE. A BLEVE can occur when a flammable liquid inside a container is exposed to fire. The book, *Loss Prevention in the Process Industries*, provides the following description of a BLEVE:

> When a vessel containing a liquid under pressure is exposed to fire, the liquid heats up and the vapour pressure rises, increasing the pressure in the vessel. When this pressure reaches the set pressure of the pressure relief valve, the valve operates. The liquid level in the vessel falls as the vapour is released to the atmosphere. The liquid is effective in cooling that part of the vessel wall which is in contact with it, but the vapour is not. The proportion of the vessel wall which has the benefit of liquid cooling falls as the liquid vaporizes. After a time, metal which is not cooled by liquid becomes exposed to the fire; the metal becomes hot and then may rupture.[16]
>
> * * *
>
> The essential features of a BLEVE are (1) the vessel fails, (2) the failure results in a flash-off of vapour from the superheated liquid and, if the liquid is flammable, (3) the vapour ignites and forms a fireball.[17]

3.3.2 Events Leading to the BLEVE at the Farm

Once the leaking propane ignited, fire, fed by the broken liquid line, engulfed the tank. As the fire burned, the flames heated the walls of the tank above the liquid level, causing changes in the properties of the tank material. At the same time, heat from tank surfaces located below the liquid level was transferred rapidly to the propane, causing it to boil. As the propane boiled, the pressure inside the tank increased because of the expanding vapors. Approximately 10 minutes after the fire started, the pressure increase caused the relief valves to open to vent excess pressure

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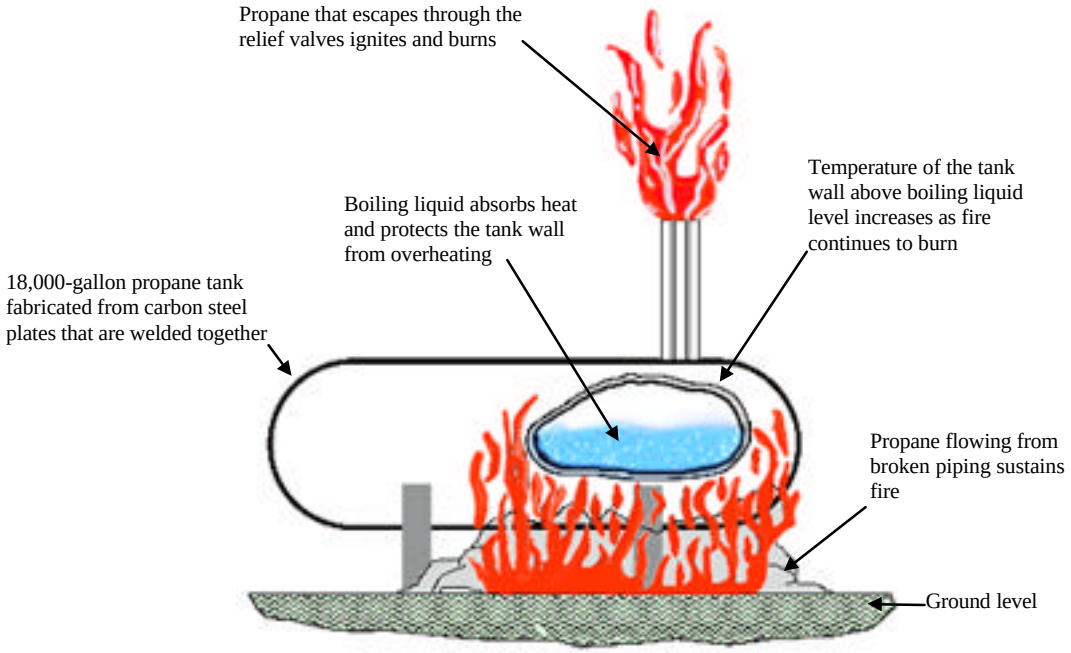
[16] Lees, Frank P. *Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control*, 2nd ed.; Butterworth-Heinemann: Oxford, England; 1996, Vol. 2, 17/177.
[17] *Ibid*. at 17/178.

from the tank. After about 18 minutes, when the overheated tank wall lost sufficient strength and could no longer resist the pressure-induced forces, fracture initiated. Because there was no liquid propane near the top of the tank to absorb the heat, fracture probably initiated at a point above the liquid level, where the tank wall was the hottest.

Immediately after the initial fracture in the tank wall, the following events occurred within moments. The remaining propane inside the tank began escaping into the surrounding atmosphere, where it vaporized almost instantaneously. As the liquid and vapors escaped, the tank wall continued tearing, allowing even more propane to escape. The propane ignited, and the explosion occurred. Tank fragments were propelled in all directions. Figure 9 shows the conditions that produced the BLEVE.[18]

[18] Kletz, Trevor. *What Went Wrong? Case Histories of Process Plant Disasters*, 2nd ed.; Gulf Publishing Company: Houston, Texas; October 1988, 112-120.



Boiling Liquid Expanding Vapor Explosion (BLEVE)

1. After the piping is broken, propane begins leaking from the tank and flows along the ground surface.
2. Soon after ignition of the leaking propane, a fire burns out of control in the vicinity of the 18,000-gallon tank.
3. The fire heats the propane inside the tank, causing it to boil and vaporize.
4. The pressure inside the tank increases as the temperature of the propane increases.
5. When pressure inside the tank reaches about 250 psi, the relief valves open to vent the tank. The propane escaping from the relief valves ignites and burns.
6. As boiling continues, the pressure inside the tank exceeds 250 psi, the temperature of the tank wall increases, and the strength of the steel used to construct the tank decreases.
7. At some point, the weakened steel can no longer resist pressure-induced forces inside the tank so the wall of the tank ruptures, allowing propane to escape rapidly into the surrounding atmosphere.
8. Immediately following rupture, the escaping propane ignites, resulting in an explosion that causes the tank wall to separate into at least 36 pieces. Fire quickly consumes the remaining propane.
9. Tank fragments are propelled at a high velocity in many different directions.

Figure 9. BLEVE

3.4 DISPERSAL OF TANK FRAGMENTS AND DAMAGE TO PROPERTY

3.4.1 Dispersal of Tank Fragments

The explosion dispersed tank fragments in all directions. Four large pieces caused most of the destruction. One of the largest pieces of the tank (approximately 23 feet long and 9 feet in

diameter) was propelled to the east, through the end of a turkey barn wall (see Figure 2, item 1f) and came to rest inside the barn (see Figure 10). This piece, which represented about one-half of the tank, caused the damage to the west end of turkey barn 1f, shown in Figure 11. A second large fragment traveled north, causing the damage to another turkey barn shown in Figure 12. (See also Figure 2, item 1g for location of the barn). Two other large pieces traveled in a northwesterly direction and landed between a workshop and a feed storage bin. One of these pieces likely caused the damage to the two-story workshop shown in Figure 13. Smaller tank pieces traveled in various directions. Some of these pieces were discovered in the grain fields that surround the property. A map that depicts the location of tank debris following the explosion is provided in Appendix C.

3.4.2 Damage to Property

The explosion caused approximately $240,000 damage to buildings located on the farm.

Figure 10. Piece of 18,000-gallon Tank Inside Turkey Barn (1f)

Figure 11. Damage to West End of Turkey Barn (1f)

Figure 12. Damage to Turkey Barn (1g) Caused by Impact of Large Tank Fragment

Figure 13. Southeastern View of Damage to Workshop Caused by Impact of Large Tank Fragment

3.5 METEOROLOGICAL INFORMATION

The temperature at the time of the incident was approximately 38°F. The relative humidity was 86%. The wind was 10 mph and blowing to the northwest. This weather information was recorded at 10:53 pm at the Spencer, Iowa, municipal airport. Spencer is located fewer than 30 miles northwest of the farm.